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DUAL NETWORKS OF KNOWLEDGE FLOWS: AN EMPIRICAL TEST OF COMPLEMENTARITY IN THE PREPACKAGED SOFTWARE INDUSTRY

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Abstract

In this paper, we develop a model of complementarity of knowledge flows in software ecosystems through two knowledge-acquisition mechanisms: a formal, fine-grained, contractual governance mechanism through inter-firm alliances and a nonformal, course-grained, noncontractual mechanism of spillover capture. In contrast to studies that focus solely on knowledge exchange in alliances, we focus on two mechanisms and test their additive and super-additive effects in the software sector. We examine the effect of a software firm's position in the alliance network (formal, contractual mechanism) and patent citation network (nonformal, non-contractual mechanism) using two important network characteristics: reach and redundancy. We test our model using data on the packaged software industry during the period 1995 to 1999. Our results show that software firms' sales performance is predicted by their positions within these two networks. Furthermore, we find that these network positions are additive and complementary in their impact on performance. Our results are potentially generalizable to other settings that have interdependent information and knowledge flows across organizational boundaries.

Keywords: Knowledge management, network analysis, complementarity, governance mechanism, patent citation network, alliance network, design science, software ecosystems

Introduction

A firm's performance depends upon its internal capabilities and knowledge resources (Conner and Prahalad 1996; Teece et al. 1997) and its ability to access critical complementary resources from other firms within its ecosystem (Gulati and Gargiulo 1999). Firms exploit their own, existing knowledge and explore others' knowledge to generate new knowledge (Cohen and Levinthal 1989; March 1991; Nonaka and Takeuchi 1995). They sustain their competitive advantage through their ability to reconfigure their knowledge (Henderson and Cockburn 1994; Kogut and Zander 1992; Teece et al. 1997).

Software is an ideal setting for studying interfirm knowledge flows because it is an example of system-based competition. Firms are interdependent as they cooperate with each other and differentiate from competitors (Shapiro and Varian 1999). Thus, a network of relationships is key for a software firm's success (Campbell-Kelly 2003). In this study, we develop a conceptual model of a software firm's position in two complementary networks that reflect different governance mechanisms and exploit different knowledge flows. The alliance network represents a formal, contractual mechanism (henceforth referred to as the contractual network) for accessing fine-grained knowledge (Gulati and Gargiulo 1999). In addition, firms access and leverage knowledge through nonformal, noncontractual mechanisms (henceforth referred to as the noncontractual network) such as informal trading by employees (Saxenian 1991), borrowing from others (March and Simon 1958, p. 209), and capturing spillover (Cohen and Levinthal 1990). Such mechanisms may be better suited for coarse-grained knowledge (Gulati and Gargiulo 1999). We operationalize spillover capture through patent-citations (Trajtenberg 1990).

Prior research on networks in general, as well as software networks in particular, have focused on one mechanism (for information on alliance networks, see Ahuja 2000a; for information on patent networks, see Podolny and Stuart 1995) to the exclusion of other mechanisms that firms employ to access complementary knowledge resources (for an exception, see Powell et al. 2005). Our interest is in exploring both the independent and additive impact of a firm's position in the contractual and noncontractual networks on its performance. These networks represent alternative mechanisms for knowledge access by firms.

Theoretical Perspectives and Hypotheses

Accessing Complementary Knowledge: Two Mechanisms

Firms succeed by effectively accessing complementary knowledge resources from entities in the broader ecosystem (Sorenson and Stuart 2001; von Hippel 1988). In the knowledge-intensive biotechnology sector, Powell and his colleagues (Powell, Koput, and Smith-Doerr 1996; Powell et al. 2005) have shown that linkages between a firm and its set of partners—whether formal alliances, licensing, or otherwise—are key conduits for obtaining access to external knowledge. An important finding from that stream of work is that there is no single linkage that governs effective knowledge flows across contexts and time, thus calling for a more comprehensive, holistic approach that recognizes multiple avenues of knowledge access.

In this vein, we focus on two mechanisms. One is interfirm alliances and relationships that are governed by formal mechanisms of resource pooling and value appropriations (Gulati and Singh 1998). Alliances include license sharing agreements, joint ventures, research consortia, joint research and development activities, and other activities governed by the alliance agreement. Software companies create interconnections for many reasons, such as access to financial capital, specialized knowledge, complementary assets, technical capabilities, and new marketing channels (Oliver 1990). For these reasons and others, software firms form relationships with other firms and such moves create the network of relationships that act as the backdrop for competition and value delivery in this industry. We term this the *formal, contractual* mechanism.

The other mechanism recognizes the more nonformal interconnections that exist between companies. This may involve informal trading of know-how between employees in an industry (Saxenian 1991) as well as relying on innovations by lead users (von Hippel 1988). It could also involve borrowing best practices through participation in best-practice consortia and membership in industry associations (Rosenkopf et al. 2001). Other practices of accessing and using knowledge from others—albeit in a course-grained way—are reverse engineering, product examination, and sharing of customers. These mechanisms all represent the capture of spillover (unintended knowledge sharing) (Cohen and Levinthal 1990). We term this the *nonformal, noncontractual* mechanism.

Network Characteristics: Two Key Positions

Networks have become an important focus of attention in recent years (Ahuja 2000a; Burt 1992; Freeman et al. 1991; Powell, Koput, and Smith-Doerr 1996; Uzzi 1996). Researchers utilize a variety of constructs to measure network characteristics as well as a specific firm's access to resources from other firms. We utilize two constructs to capture network position: *reach* and *redundancy*. A firm that has access to the largest number of other firms in the fewest number of steps is considered to have the greatest reach. When a firm forms relationships with otherwise connected firms it is said to have redundancy.

Thus, our conceptualization involves two mechanism (formal, contractual and nonformal, noncontractual) and two characteristics (reach and redundancy). We develop four hypotheses on the role of these network positions on software company performance.

Hypothesis 1: Knowledge Flows Through Formal, Contractual Mechanisms

Role of formal, contractual reach in software networks. Firms access knowledge through their direct relationships as well as indirect relationships (Ahuja 2000a). Better performing firms have ties to more diverse knowledge sources and are better positioned to access key information and critical resources (Powell, Koput, and Smith-Doerr 1996). We are beginning to see some consistent, cumulative empirical findings that a firm's position within a network of alliances contributes to innovation (Ahuja 2000a; Powell, Koput, and Smith-Doerr 1996) and to its subsequent sales and financial performance (Powell et al. 1999). While most of these findings have been based on studies in industries such as chemicals (Ahuja 2000a), steel (Rowley et al. 2000), financial services (Baum et al. 2000), and manufacturing (McEvily and Zaheer 1999), the role of interfirm alliances for knowledge

access in the software industry is conspicuously absent. Since this industry is characterized by the need for interfirm coordination in the launch of products due to requirements of interoperability, as well as changes in the industry, alliances have been growing steadily in importance (Campbell-Kelly 2003; Cusumano 2004). We expect that a software firm's performance will be explained significantly by its strategic choice to enter into a set of alliances reflected by its reach in the alliance network.

H1a: Reach in the formal, contractual network is positively associated with performance.

Role of formal, contractual redundancy in software networks. Successful firms increase their access to unique knowledge and rare resources through alliances. A network of ties is formed as focal firms' partners form ties among themselves. If a firm's partners share knowledge, some of the knowledge the focal firm receives will be redundant. The tie between the focal firm's partners decreases the uniqueness of the knowledge that would otherwise be available from the focal firm's alliance partners. From this perspective, ties among a firm's alters increase the redundancy of the focal firm's alliance network and negatively impacts its performance.

However, firms both cooperate and compete with each other. As a result, each firm has an ongoing imperative to maintain a differentiated set of products, services, and customers. Moreover, in order to maintain differentiation, each firm develops its own unique competencies by investing in its own internal R&D activities. Thus, even within a closed network in which a firm's partners are also in alliance with each other, each firm has access to new knowledge, internally developed. This mitigates the negative effects of redundant alliances on new knowledge acquisition. Redundant alliances could even facilitate sensemaking and enhance all the firms' ability within the closed network to respond and adapt to fast-changing technological environments (Krackhardt and Stern 1988; Rindfleisch and Moorman 2001).

The preceding argument, however, addresses value creation, not value appropriation. In order to understand how a firm performs, we need to consider the competitive landscape in which firms cooperate and compete (Baum and Singh 1994; Silverman and Baum 2002). Firms in alliance may help each other identify opportunities, and even provide complementary products. Firms enter into alliances in order to access resources and competencies they do not have internally. They enter into alliances to coordinate product development and launch activity. Firms in dense clusters (where each firm has an alliance with every other firm in the cluster) would seem to provide a bundle of products often purchased as a unit by the customer. Such a scenario may limit the firm's ability to independently set prices or expand its market. Thus, while alliances can be beneficial, redundancy in alliances is a form of social constraint (Portes and Sensenbrenner 1993).

H1b: Redundancy in the formal, contractual network is negatively associated with performance.

Hypothesis 2: Knowledge Flows Through Nonformal, Noncontractual Mechanisms

Role of nonformal, noncontractual reach in software networks. Since von Hippel's (1988) finding on the role and prevalence of informal trading, there has been considerable interest in nonformal mechanisms for know-how exchange. Network researchers have recognized nonformal mechanisms through membership in common boards as imitative ways to understand practices (Galaskiewicz and Wasserman 1989). Economic researchers have focused on how firms develop superior knowledge through internal R&D activities and learn from others through spillover effects (Cohen and Levinthal 1989). In fact, due to the nature of knowledge, they need to do internal R&D to create the necessary absorptive capacity to maximize the value of spillover. Firms seek access to coarse-grained knowledge from spillovers through a variety of mechanisms—through participation in conferences, tradeshow, and professional organizations; reading each other's publications; studying each other's patents, products, and other innovations; and hiring each other's employees.

Reach in informal network reflects the breadth of knowledge sources accessed as organizations strive to balance exploration of new domains with the exploitation of current domains (March 1991). In general, lower reach in nonformal networks reflects a conservative posture to limit knowledge to familiar domains while a higher level of reach signals a company's desire to seek, access, and internalize knowledge from newer domains. Using patent citations as an operationalization of nonformal access to knowledge, Rosenkopf and Nerkar (2001) found that, in their study of the optical disk industry, the impact of exploration on technological development beyond the optical disk domain was the greatest when exploration spanned organizational and technological boundaries—providing support for our hypothesis.

H2a: Reach in the nonformal, noncontractual network is positively associated with performance.

Role of nonformal, noncontractual redundancy in software networks. If the focal firm is accessing the knowledge of two other firms, A and B, which are accessing each others' knowledge, then there is some overlap in the knowledge that the focal firm is accessing. Some of the knowledge that the focal firm gains from firm A is indirect knowledge from firm B, which the focal firm is also getting directly. Network research literature considers the focal firm to have redundant ties.

Redundant ties reduce the firm's access to non-overlapping knowledge flows (Burt 1992). Given two firms with the same reach, the firm with fewer redundant ties has access to more unique knowledge. Moreover, firms with fewer redundant ties are more likely to be less constrained in their ability to enter into new markets. Although redundant ties can foster trust (Ahuja 2000a; Coleman 1988), trust would not seem too valuable in appreciating spilt knowledge. There is no exchange relationship in which either party in an inadvertent knowledge sharing relationship has an expectation of performance on the other party. Therefore, we predict

H2b: Redundancy in the nonformal, noncontractual network is negatively associated with performance.

Complementarity in Dual Networks: Additivity and Super-Additivity

Additivity Hypothesis

Firms require multiple types of knowledge. Some of the knowledge can be developed internally and some can be accessed or acquired through external sources. External knowledge can be accessed through contractual linkage, noncontractual linkage, acquisition (hierarchy), and the market. Each knowledge source has different costs and trade-offs. Successful firms attempt to select their knowledge sources so as to maximize the knowledge at their disposal given their cost or budget constraints.

The knowledge that flows from one firm to another may be technical, managerial, or market oriented. Industry differences influence the type and amount of knowledge that flows between firms. The mechanisms that firms use to protect valuable intellectual property (Levin et al. 1987) within different industries may also influence the type of knowledge available in each network. In addition, the value of external knowledge and the degree of difficulty associated with locating it, accessing it, and then internalizing it may influence the likelihood of link formation in both the contractual and noncontractual networks.

Ceteris paribus, networks of formal linkages through contractual relationships are different from networks of nonformal, noncontractual relationships. This is because firms seek to develop a portfolio of mechanisms that delineate the set that maximize value from such governance modes while minimizing transaction and coordination costs (Gulati and Singh 1998). Therefore, if a firm exists in both networks, it is because the firm is receiving distinct benefits from each. By invoking the thesis of effectiveness of governance modes (Williamson 1975), we expect that the value from these different networks will be independent and additive.

H3a: Reach in the contractual and noncontractual networks are additively associated with performance.

Super-Additivity Hypothesis

The new knowledge that a firm creates by applying its absorptive and recombinative capabilities (Kogut and Zander 1992) to externally sourced knowledge makes the firm more attractive to network partners in both the contractual and noncontractual networks. Attractive partners are those that have unique knowledge and other resources, and firms will only create ties to attractive partners. The dynamics of network growth are similar in each network. Knowledge and status developed through position in one network improve the prospect of the firm in the other.

Complementarity in Position

Technological capabilities and resources developed internally and acquired through spillover make the firm more visible and attractive to potential alliance partners (Ahuja 2000b; Rosenkopf et al. 2001). The firm's position in the alliance network can be enhanced through its internal knowledge generation efforts, through its knowledge generation efforts facilitated by its noncontractual ties, and through endogenous improvement as the firm uses its existing network connections to learn about new partnership opportunities (Gulati and Gargiulo 1999). Thus, competencies developed in the noncontractual network will complement the firm's efforts to enter into alliances.

The firm's activities in the alliance network will enable it to create new products (Kotabe and Swan 1995; Rothaermel 2001; Rothaermel and Deeds 2004) and enter new markets. By creating new venues for innovation, such new product and market entry generates demand for additional information from the noncontractual network. As the firm seeks additional spillovers, it seeks new firms from which to learn. As it accesses these firms' spillover, it improves its position in the noncontractual network. Thus, competencies developed in the contractual network will complement the firm's efforts in the noncontractual network.

As the firm develops its internal capabilities, possibly developed in part through alliances, it becomes interested in the products, innovations, and strategies of other firms. The examination of one firm's products and innovations may lead to the examination of related firms' products and innovations. Thus, the firm's position in the noncontractual network is also the result of exogenous and endogenous tie formation as the firm develops ties based upon learning through the alliance network and its existing position within the noncontractual network. Thus, the two networks are complementary in how they facilitate improvement in network position.

Complementarity in Knowledge

We have previously characterized the resources that the contractual and noncontractual networks provide access to as being distinct. We now assert that resources available from the two networks are complementary. Following Haunschild and Beckman (1998), the information from the two networks have different characteristics. Information gathered from alliances has the potential for being far more tacit or process-oriented than the information gathered through spillover capture because alliances allow for fine-grained information exchange and spillover capture does not. Alliance partners expend the effort and resources in an alliance to gain access to resources that complement their own (Powell, Koput, and Smith-Doerr 1996). Firms with process knowledge but without product knowledge and firms with product knowledge but without process knowledge are both in a weaker position than firms with both, all else being equal.

We anticipate that because a firm's reach in the contractual and noncontractual networks facilitate improvement in the firm's reach in the other, and because the information and resources from the different networks are likely to be super-additive (Milgrom and Roberts 1990), firm performance will benefit from the joint position of the firm in the contractual and noncontractual networks. More formally,

H3b: Dual networks (contractual and noncontractual) are super-additively associated with performance.

Research Setting: The Software Industry

The software industry is a textbook example of systems-based competition (Shapiro and Varian 1999) that calls for high levels of interoperability (Baldwin and Clark 1997) with complementors. Firms form alliances to develop new products, align product features, and coordinate release cycles. The information that flows noncontractually includes product features, software development processes, market information, and customer data. One type of spilled, noncontractual information—technological innovations—is documented through patents. Software patents represent over 15 percent of all patents granted and account for over 25 percent of the total growth in the number of patents granted between 1976 and 2001 (Bessen and Hunt 2003). Thus, the availability of data representing both contractual and noncontractual knowledge exchange makes software an ideal setting to test the theory of additivity and super-additivity

Dataset

We assembled a research database of firms in the prepackaged software industry (SIC code 7372) during the period 1995 to 1999¹ by combining data from multiple sources. Space limitations prevent a detailed discussion, but an appendix is available upon request. Our sample frame consists of the 77 firms that were in the top 50 firms (by sales) in at least 1 year of our sample timeframe. For the 77 firms we have 254 firm/year observations. These firms cite 3,843 other non-focal firms (also included in our dataset, but not necessarily in SIC 7372). Our 77 focal firms applied for 3,891 patents during 1995-1999 that were

¹This time frame represents one of the more turbulent times in the software industry due to shifts resulting from various technological innovations (e.g., client-server computing, ERP, and the run-up to the Y2K problem). However, all firms faced the same environmental conditions.

subsequently granted. The non-focal firms applied for 314,026 patents during this same time period that were subsequently granted. We also collected alliance data on the focal firms and their alliance partners from the SDC Corporation database. For every alliance and its participants (i.e., ultimate parent), we extracted the type and year of the alliance. Our 77 focal firms announced 1,669 alliances between 1995 and 1999 with 1,127 non-focal alliance partners. We selected only those arrangements that involved significant knowledge transfer.

Methodology

Because we have more firms than years in our sample, we utilize a cross-sectional approach to assess our hypotheses. However, because we do have multiple years in our sample, we can strengthen the validity of our results through the use of a panel design. Due to the significant differences between firms in both size and network position, we anticipate that the regressors in our model will explain different amounts of variance across firms, resulting in a heteroskedastic error term across panels. Therefore, we test the hypotheses using a cross-sectional time-series model using generalized least squares so that we can estimate in the presence of heteroskedasticity across panels (Green 2003). Our specific regression model, research setting, and data are described later in this paper.

Network Construction

Alliance Network

A number of researchers have constructed alliance networks (Ahuja 2000a; Powell, Koput, and Smith-Doerr 1996). Our approach is appreciably the same as theirs with the exception, as noted above, that we included firms in the alliance network outside the focal firms' industry. We define the software alliance network as a dynamic, undirected, dichotomous (binary) graph with node and edge sets N_t and E_t respectively. The firms that can enter N are one of our 77 focal firms or one of the 1,127 non-focal alliance partners. A firm is in N_t if it is a participant in an alliance announcement during time $[t-2, t]$. We assume alliances last 3 years² because they are generally multiyear and alliance terminations are rarely reported. An edge is added to E_t connecting two nodes in N_t if the two nodes were in the same alliance during time $[t-2, t]$. The network contains alliances between focal firms, between focal and non-focal firms, and between non-focal firms.

Patent Citation Network

Patent citations are seen as a measure of technological significance by the Office of Technology Assessment and Forecast as well as an important mechanism of seeing innovation as a continuous and incremental process (Trajtenberg 1990). Researchers use patent citations as a measure of knowledge and to represent learning through a process of capturing spillover (Ahuja 2000a; Cockburn and Griliches 1988; Griliches 1990; Jaffe and Trajtenberg 2002; Jaffe et al. 1993; Podolny and Stuart 1995; Stuart 1999). Although software patents are new, controversial, and may reflect rent-seeking rather than the protection of intellectual property, they continue to reflect the technological antecedents of innovations in their citation lists.

Our focal firms share the same appropriation regime, the same patenting incentives and costs, and (in our construction) similar proclivities to patent. We are studying software firms that patent, not software patents. Clearly, there is far more noncontractual knowledge spilling than is represented by patents. Thus, our results under-represent spillover capture in the noncontractual network.

We define the patent citation network as a dynamic, directed, dichotomous (binary) graph with node and arc sets N_t and A_t respectively. The firms that can enter N are one of our 77 focal firms or one of the 3,843 non-focal firms assigned a patent that one of our 77 focal firms' patents cite. A firm is in N_t if it applies for a patent in time t that is subsequently granted or if it is assigned a patent that is cited in time t by a node in N_t . An arc is added to A_t connecting two nodes A and B in N_t if firm A applies for a patent in time t that cites a patent assigned to firm B . The network contains arcs between focal firms, between focal and non-focal firms, and between non-focal firms.

²We did not test the sensitivity of results to this assumption.

Operationalization of Constructs

Performanceⁱ_t. Our dependent variable is software firm performance, operationalized by firm sales. Our sample firms are all primary SIC code 7372 (prepackaged software). Sales as a proxy for firm performance have been used in some recent studies (in particular, see Powell et al. 1999). We measure a software firm's sales as company *i*'s total revenues (in millions) in year *t*. The range for *t* for this study is 1995 to 2000. Due to the range of revenues in the software industry (even among the top 50 firms), we used the logarithm of the raw revenue numbers.

Alliance Network Reachⁱ_{t-1}. We measure a company's reach by calculating its degree centrality. The alliance degree centrality (Wasserman and Faust 1994) of company *i* in year *t-1* measures the number of direct ties to other companies in the network in year *t-1*. We calculate the degree centrality by counting the number of edges involving company *i* in time *t-1*. Due to the range of degree centrality measures in our network, we used the logarithm of the raw measure.

Patent network reachⁱ_t. We measure patent network reach through the firm's degree centrality in the patent citation network. The patent degree centrality (Wasserman and Faust 1994) of company *i* in year *t* measures the number of direct ties to other companies in the network in year *t*. We calculate the degree centrality by counting the number of arcs originating at company *i* in time *t*. We assume that the knowledge access that resulted in the patent application in time *t* occurred in time *t-1*. Due to the range of degree centrality measures in our network we used the logarithm of the raw measure.

Alliance network redundancyⁱ_{t-1}. Alliance redundancy is measured by the clustering coefficient of the firm's ego³ network within the alliance network. The alliance clustering coefficient of company *i* in year *t-1* measures the degree to which a company's alliance partners are also partners with each other (Watts 1999). We calculate the clustering coefficient by dividing the total number of edges between company *i*'s partners in time *t-1* by the total number of possible edges between those partners (Wasserman and Faust 1994).

Patent network redundancyⁱ_t. We measure patent network redundancy through the clustering coefficient of the firm's ego network within the patent citation network. The patent clustering coefficient of company *i* in year *t* measures the degree to which a company's alters are also alters of each other (Watts 1999). We calculate the clustering coefficient by dividing the total number of arcs between company *i*'s alters in time *t* by the total number of possible arcs between those nodes (Wasserman and Faust 1994). We assume that the knowledge borrowing that resulted in the patent application in time *t* occurred in time *t-1*.

Patent and alliance network reach super-additivityⁱ_{t-1}. We create a variable to measure complementarity between position in the alliance network and position in the patent citation network by calculating an interaction term for our regression model. The interaction variable is calculated by multiplying *alliance degree reachⁱ_{t-1}* and *patent degree reachⁱ_t*.

Controls. We calculate the total revenue of all firms in SIC 7372 for year *t* to control for general industry growth and price changes. We measure company age in year *t* as the difference between the year *t* and the firm's incorporation date. To control for differences in patenting opportunity due to firm-specific research interests, we control for technical opportunity. We calculate technical opportunity by creating an industry vector of patenting activity, the focal firm's vector of patenting productivity, and then calculate the Pearson correlation coefficient between the two vectors. This measures the distance between the firm and the industry average in time *t*. In each year *t*, we create a vector with one dimension for each patent class. For each class, we count the number of patents applied for in year *t* subsequently assigned to that class. To create the industry vector, we utilize all patents in our dataset. To create each firm's vector, we utilize the firm's patents. We assume that the resulting technical opportunity measure reflects the opportunity in time *t-1* because of the lag between performing research and applying for the patent.

To control for the possibility that different patterns of alliance activity were more valuable than others, we control for alliance diversity. We calculate alliance diversity by creating an industry vector of alliance activity, the focal firm's vector of alliance activity, and then calculate the Pearson correlation coefficient between the two vectors. This measures the distance between the firm and the industry average in time *t-1*. In each year *t-1*, we create a vector with one dimension for each alliance type (using the SDC coding). For each type, we count the number of alliances coded in year *t* to that type.

³An ego network consists of a focal node ("ego"), the nodes directly linked to ego (the "alters"), and the links among the alters.

Analysis

We build our model additively in five stages to examine the specific performance effects of a firm's set of network characteristics. The independent variables are lagged by one year under the assumption that there is a lag between access to knowledge and the development of capabilities and firm performance. In model 1, we consider industry and firm controls. In model 2, we add variables that represent the firm's position in the alliance network. In model 3, we replace the alliance network measures with patent citation network measures in order to consider the importance of each network independently. In model 4, we combine the network measures from both the alliance and patent citation networks in order to consider their additive qualities. In model 5, we test for an interaction effect between the alliance and patent citation networks.

We use a cross-sectional time series feasible generalized regression, with heteroskedastic correction, of the form

$$Sales_t^i = V_t \alpha + W_{t-1}^i \beta + X_{t-1}^i \gamma + \varepsilon_t^i$$

The vector V_t contains industry controls (i.e., industry size). The vector W_{t-1}^i contains focal company controls (i.e., technical opportunity and alliance diversity). The vector X_{t-1}^i contains the network covariates (i.e., alliance cluster coefficient, alliance degree centrality, patent cluster coefficient, patent degree centrality).

As shown in Table 1, all models add statistically significant explanatory power. The continuous improvement in model fitness as variables are added provides support for the general hypothesis that the networks have individual, additive, and super-additive explanatory power. Controlling for the firm's position in the alliance network, its position in the patent citation network adds explanatory power. Similarly, controlling for the firm's position in the patent citation network, adding the firm's position in the alliance network adds explanatory power. Finally, the addition of an interaction variable, testing for super-additivity, improves model fitness. The hypotheses tests and general observations regarding the regression coefficients are performed with the full, final model.

Examining the coefficients of alliance degree centrality and alliance cluster coefficient, respectively, tests hypotheses H1a and H1b. A firm's reach in the contractual network has a positive effect on performance (H1a). Tie redundancy in the contractual network has a negative effect on performance (H1b). Examining the coefficients of patent citation network degree centrality and cluster coefficient, respectively, tests hypotheses H2a and H2b. A firm's reach in the noncontractual network has a positive effect on performance (H2a). Our data did not support the hypothesis that tie redundancy in the noncontractual network has a negative effect on performance (H2b). Hypothesis H3a is tested by examining the change in model fitness when going from one network to two. A firm's position in the contractual and noncontractual networks additively enhances performance (H3a). Hypothesis H3b is tested by examining the coefficient of the degree centrality interaction term. A firm's position in the contractual and noncontractual networks is super-additively associated with performance (H3b).

Discussion

This research has strategic, design, and practitioner implications. Understanding the pattern and logic of interdependence across organizations is an important area for strategy and management researchers who deal with interorganizational relationships. The view that firms have dyadic links to other firms gives way to a view in which firms are embedded in multiple, overlapping networks of relationships. Within this view, different positions in different networks have different importance. One of the many challenges facing researchers and practitioners is identifying to which networks the firm should pay attention and what role or position in each network would maximize firm performance. Some networks are, we suggest, substitutes for each other, some are substitutes for market-based transactions, and some are complementary.

The information systems research community concerned with systems that facilitate the capture, transformation, and exploitation of knowledge (Alavi and Leidner 2001) needs to be sensitive to the independent, but complementary, types of knowledge firms require, and the different mechanisms of knowledge access. Design research requires a close connection between problem understanding, problem modeling, and system development (Hevner et al. 2004). Prior research on knowledge management has placed an emphasis on the storage of knowledge elements (Alavi and Leidner 2001). From a user's perspective, it is equally important to identify relevant knowledge before attempting to capture and manage it. Thus, we need a better understanding of the knowledge environment of firms—especially the key mechanisms of knowledge access.

Table 1. Results of Tests of Hypotheses

Model	(1)	(2)	(3)	(4)	(5)
Industry size	0.162 (6.89)**	0.172 (8.19)**	0.226 (8.15)**	0.180 (7.42)**	0.189 (7.82)**
Age	0.303 (16.54)**	0.273 (11.73)**	0.314 (11.27)**	0.299 (12.44)**	0.308 (12.60)**
Alliance diversity		0.025 (0.80)		-0.019 (0.57)	-0.007 (0.20)
(H1a) Alliance network reach		0.595 (18.27)**		0.586 (17.03)**	0.522 (12.16)**
(H1b) Alliance network redundancy		-0.155 (9.47)**		-0.127 (7.07)**	-0.108 (5.46)**
Technical opportunity			0.135 (3.10)**	0.086 (1.99)*	0.084 (1.98)*
(H2a) Patent network reach			0.392 (8.17)**	0.227 (5.32)**	0.212 (5.00)**
(H2b) Patent network redundancy			-0.103 (2.74)**	-0.034 (1.22)	-0.008 (0.28)
(H3b) Reach interaction					0.054 (2.68)**
Constant	-0.009 (0.39)	0.009 (0.41)	-0.043 (1.53)	0.002 (0.07)	-0.016 (0.64)
Observations	253	253	253	253	253
Number of panels	68	68	68	68	68
Chi-Squared	284.11	1050.03	387.38	1438.61	1651.67
Log Likelihood	-237.61	-181.24	-218.44	-169.57	-165.89
Degrees Of Freedom (DF)	2	5	5	8	9
Model fitness (-2LL)	475.22	362.48	436.88	339.14	331.78
Model comparison logic		(2) – (1)	(3) – (1)	(4) – (2)	(5) – (4)
$\Delta(-2LL)$		112.74	38.34	23.34	7.36
$\Delta(DF)$		3	3	3	1
P-Value		0***	0***	0.00003***	0.00667**
Chi-squared difference test ($\Delta(-2LL)$, $\Delta(DF)$)					

Absolute value of z statistics in parentheses

Practitioners should pay attention to both the systems and strategy implications. Furthermore, they need to consider how to deploy their resources effectively and access the knowledge available through different governance mechanisms. They must then consider how to support that strategy with a complementary KMS (knowledge management systems) strategy. Our research suggests that the more successful firms recognize the overlapping, complementary nature of knowledge sources and strategically access them.

We focused on two types of networks with two characteristics. We found that a firm's position in one network does not predict its position in the other (they are independent).⁴ Network position in the two networks is complementary. We anticipated a negative impact of local clustering reflecting a reduction in brokerage opportunity and increased constraint in both networks. This hypothesis was supported in the contractual network but not in the noncontractual one.

⁴Actual regression models available from the authors. Degree centrality correlation in the two networks is significant at 0.32.

Software is a setting that calls for complex interfirm linkages. Our results show the benefits of going beyond any single avenue of resource access and the need to consider multiple gateways. This could be due to the fundamental nature of software products. Customers derive value from software by utilizing multiple, interoperable products. Our results also suggest we search for additional network frames. Candidates include interfirm equity linkages—either directly or through common venture capitalists—as well as interlocking directorates.

Network perspectives have been useful in developing insights in other fields, especially organization theory and strategic management. However, it has found limited traction within the IS field with the exception of technical IS research streams that have been concerned with data flow networks, applications, and connections. We believe that network perspectives are useful for understanding information and knowledge flows within and across organizations to guide and shape the design of knowledge management systems.

Conclusion

In this research we conceptualized a firm as embedded in two networks accessing knowledge through two different mechanisms. We tested for the performance impacts of the network positions in the two networks and found broad support for our set of hypotheses. Using data on the software industry from 1995 to 1999, we showed that the two networks are independent and complementary: the positions of firms in these networks independently and jointly explained sales performance. We hope that our results will stimulate IS researchers to adopt a network perspective to understand the flow of information and knowledge within and across organizations.

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